Grid integration of variable renewable energy

PV short-term power forecasts for system operation

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About the presenter: Albrecht Tiedemann

- Since 2009: Renewables Academy (RENAC) AG; Head of grid integration / energy policy and wind energy division; Lecturer for training programs on grid integration of renewable energy and wind energy, capacity building programs and the E-learning platform RENAC-Online
- 2003 – 2009: German Energy Agency; Project manager for grid integration of renewable energy and onshore / offshore wind energy; Chairman of the German Offshore Committee
- 1989 – 2003: Federal Environmental Agency; Scientific assistant for offshore wind energy, offshore gas / oil exploration, pulp and paper industry, life cycle assessment
- 1989: Graduated as Engineer Environmental Protection Technology at Technical University of Berlin

Agenda

1. Fundamental forecast steps
2. PV: Weather to power model
3. Forecast errors
4. Forecast implementation

AGENDA

Learning objectives

- A participant who has met the objectives of the course will be able to
  - name fundamental steps of short term photovoltaic power forecast production
  - explain forecast errors
  - calculate an example to compare the costs of balancing power with the short term PV power forecast

Learning objectives

Fundamental steps

Fundamental forecast steps

Weather Service	Forecast Provider	User

Source: B. Ernst, ReGrid-Seminar 2013

Fundamental forecast steps

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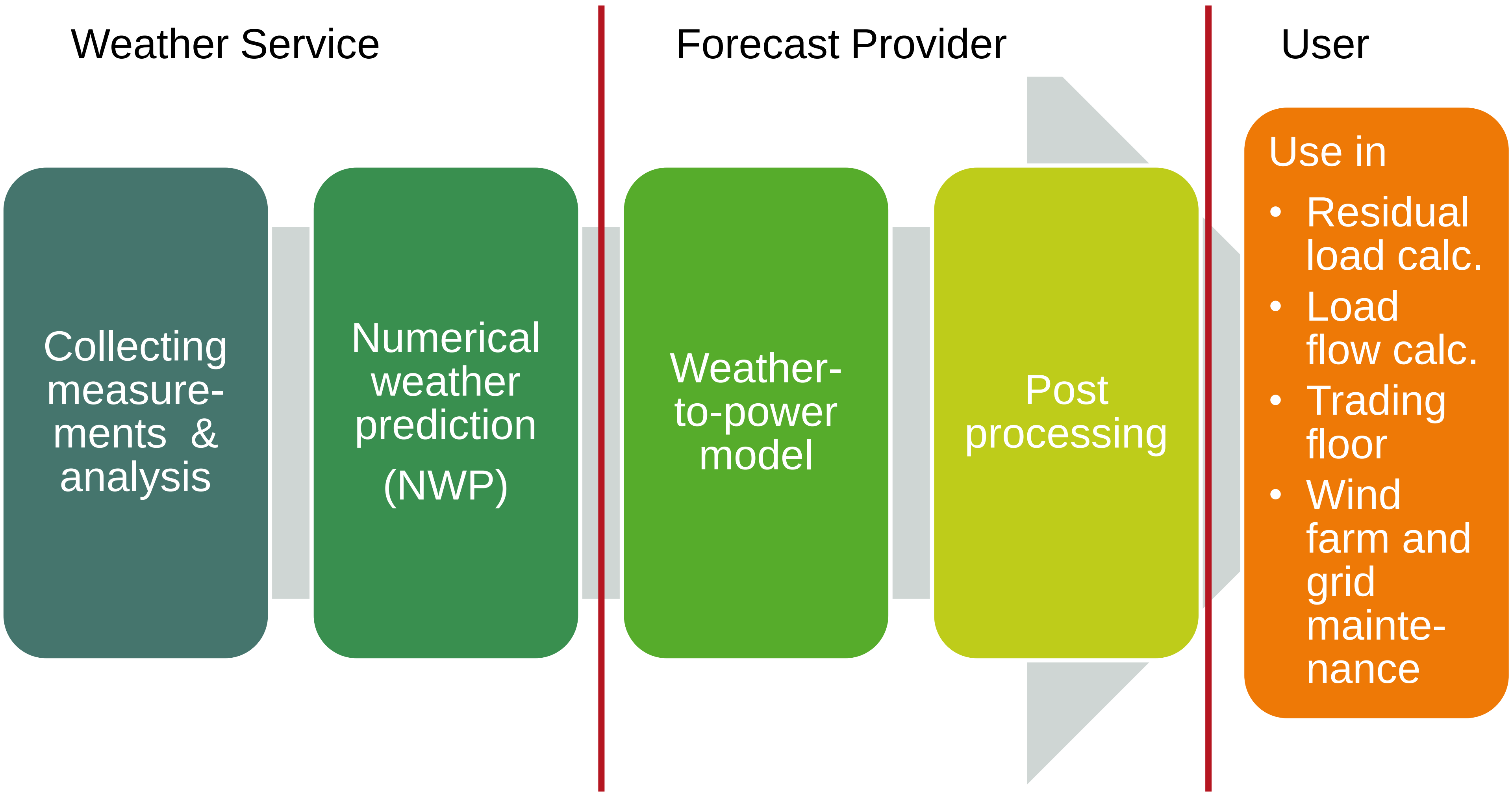
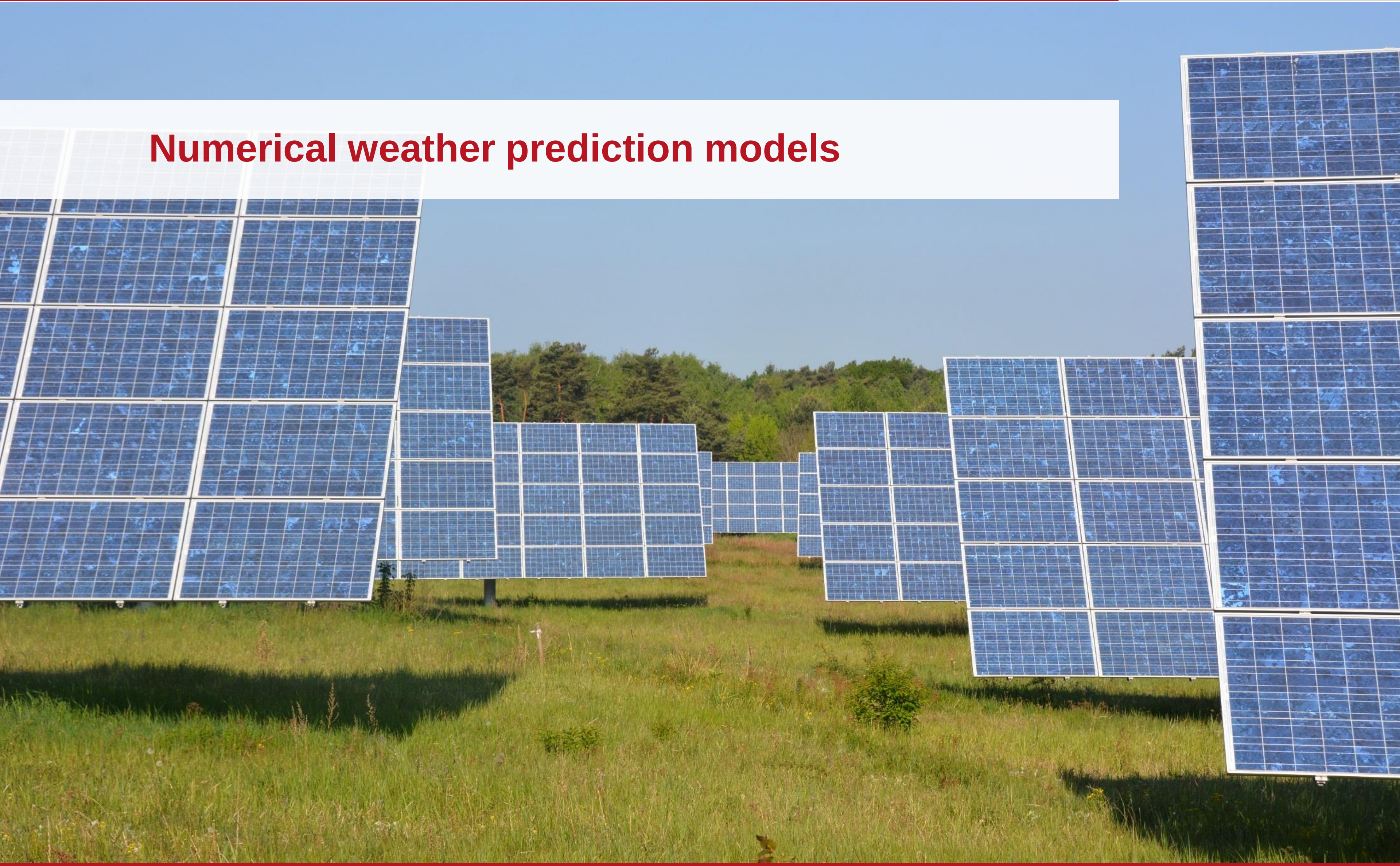
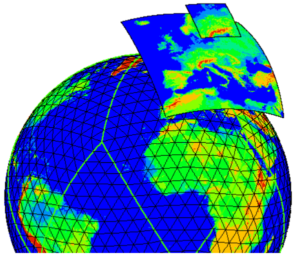


Source: B. Ernst, ReGrid-Seminar 2013

Numerical weather prediction models



Global and regional/local weather models



- A model, in this context, is a computer program that produces **meteorological information** for **future times** at **given locations** and **altitudes**
- The **horizontal domain** of a model is **either global**, covering the entire Earth, **or regional**, covering only part of the Earth.
  - **Regional models** also are known as limited-area models. Regional models are often nested inside global models and use global model output as boundary conditions. The local models run by the national weather services cover usually the on country plus the **surroundings (500 to 1,000 km**)
  - **Resolution of local models** vary **between 2 and 25 km**. In complex terrain a fine resolution leads to more accurate results but uses up more computing time
- There are a number of **international met centers** that run **global** models.
- **National met centers** and other weather providers usually run **regional** models with state estimates and bo**undary conditions from the global models.**

Source: B. Ernst, ReGrid-Seminar 2013

Grid of NWP model (example)

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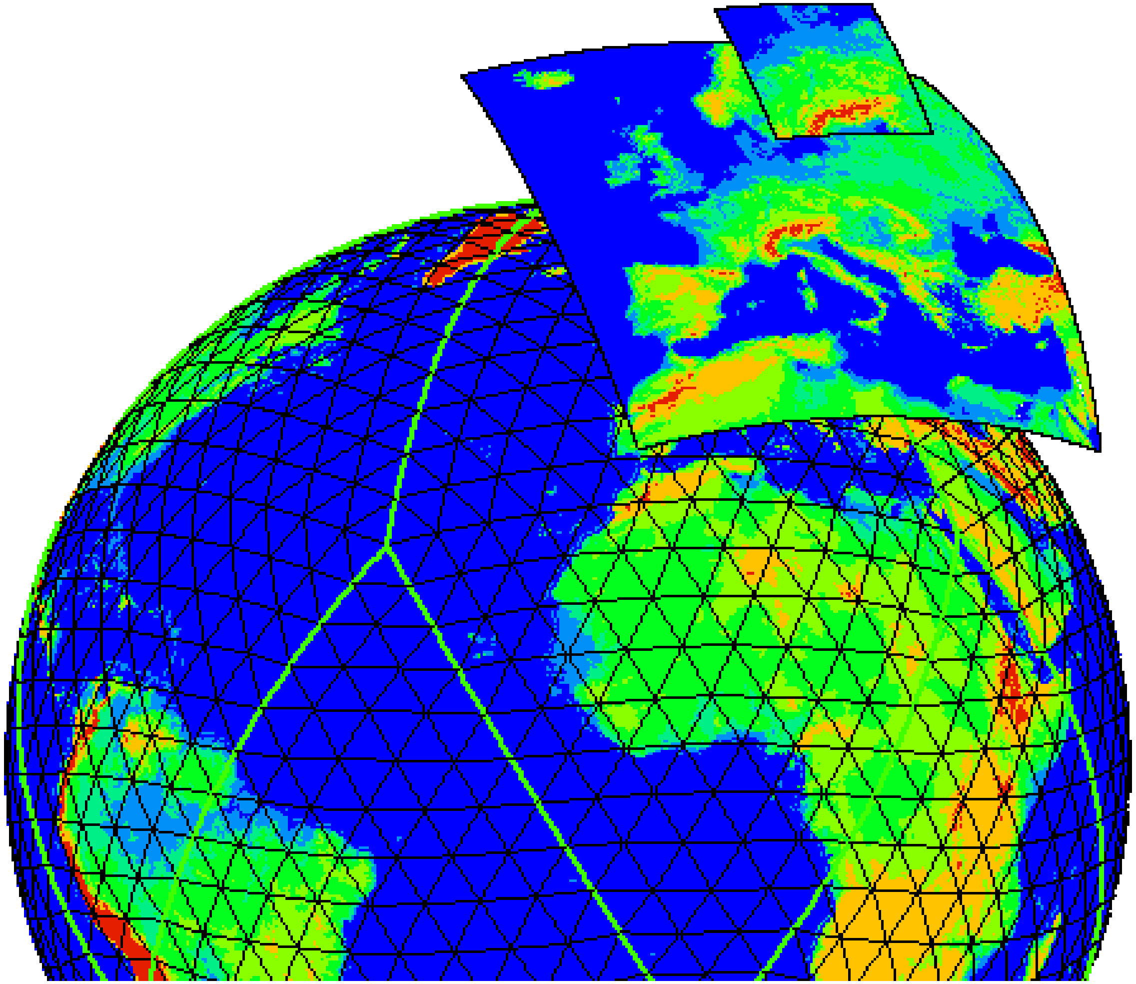
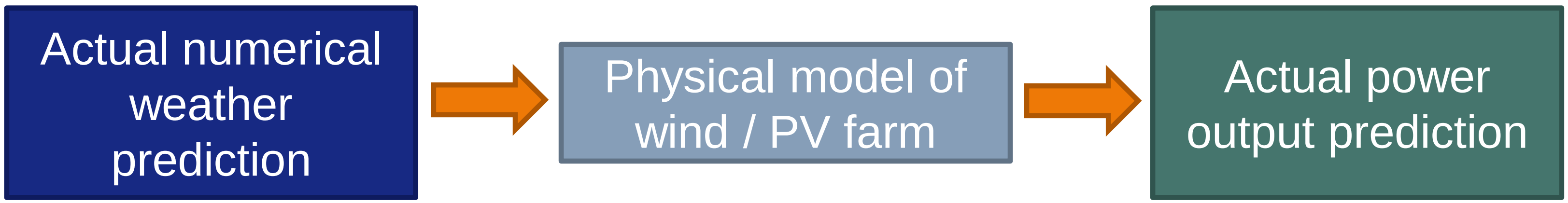


Source: B. Ernst, ReGrid-Seminar 2013

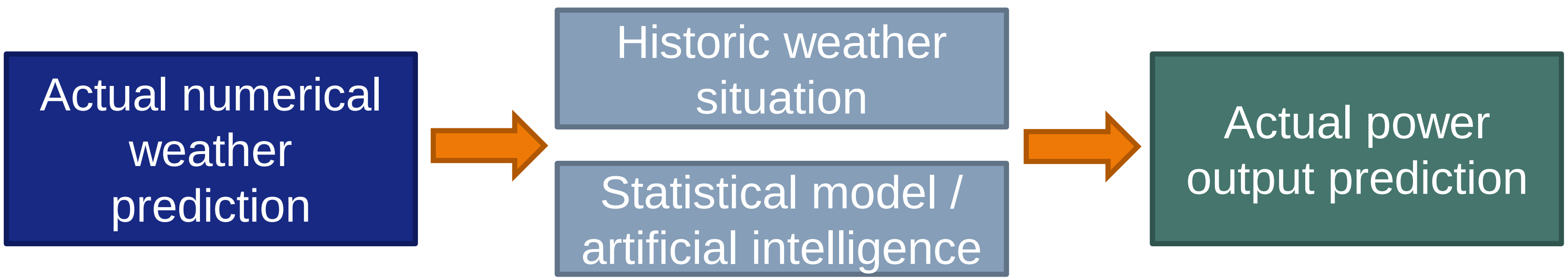
Source: DWD

Statistical and physical approach for short term forecast of wind and PV weather to power models

- Forecasting PV and/ or wind power output with physical models or



- with statistical models and historical data of wind and/or PV farms



- Methods of artificial intelligence are used: ‘Learning’ from relationship between weather forecast and PV power output (neural networks, support vector machines,…)
- Large data set of corresponding NWP and measurement are necessary (at least one year of historical data)

Advantages and drawbacks of statistical approach / physical approach for power to weather models

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- Statistical methods

  \+ no detailed physical knowledge needed

  \+ fast calculation time

  \- dependence on reliable historical data

  \- higher uncertainty at new or seldom situations

- Physical methods

  \+ quality and amount of measured data is secondarily

  \- detailed technical information about tilt angel, azimuth, tracking system, type of module, temperature sensitivity, inverter behavior, grid constraints and surrounding needed

  \- high efforts

- **Forecast providers nowadays combine both approaches**

Source: B. Ernst, ReGrid-Seminar 2013

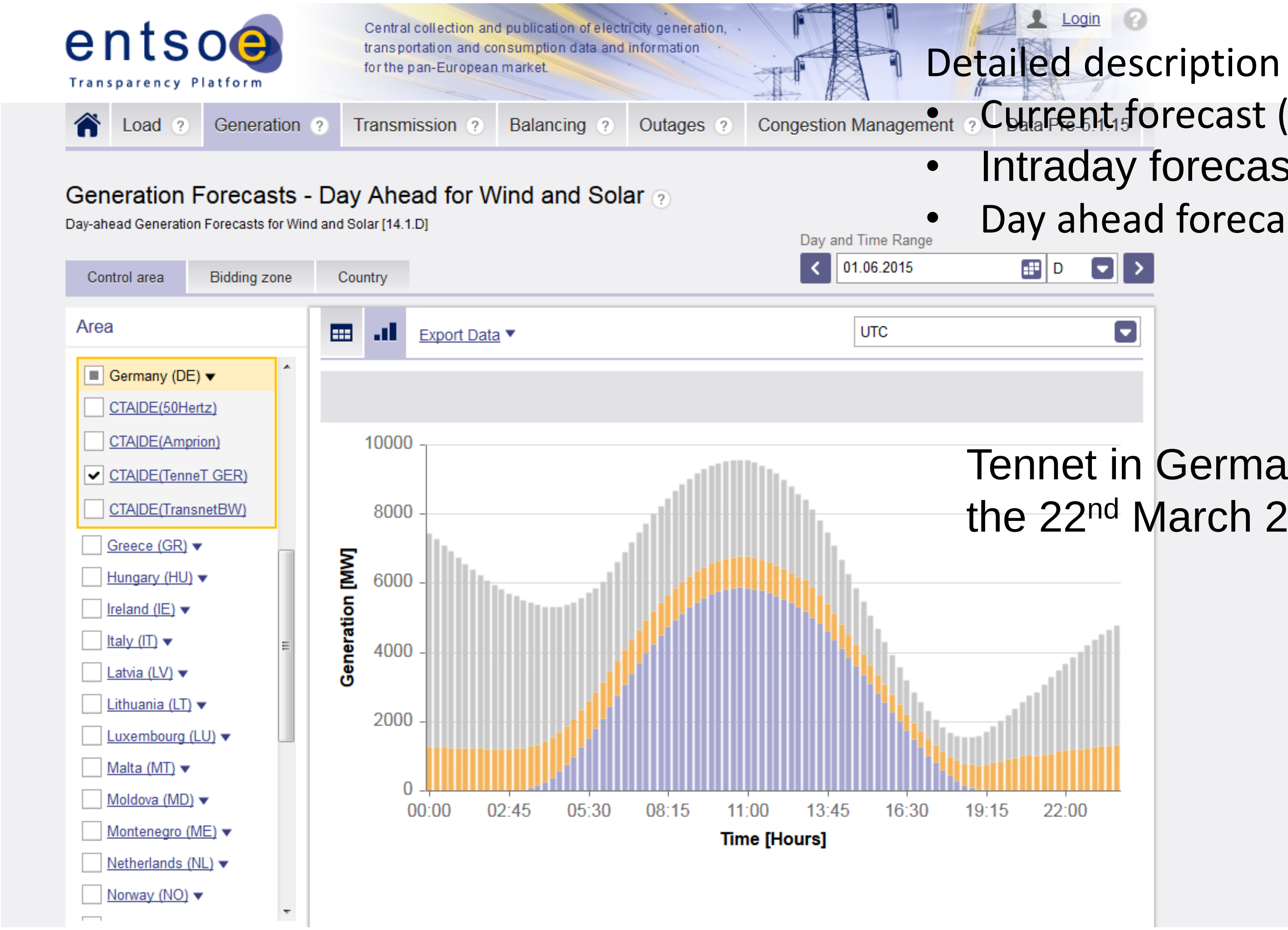
PV short-term power forecasts for system operation

PV power forecasts facts

- Time range of forecast: 0 to 10 days
- Temporal resolution: 5 minutes to 1 hour blocks
- Update: several times a day to every 15 minutes
- Integration of online measurement data for optimization of prediction
- Prediction of solar power output for
  - entire countries or regions
  - designated control areas
  - individual grid nodes
  - individual solar parks

Source: https://www.energymeteo.de/produkte/leistungsvorhersage/solarleistungsvorhersage.php

Example: Solar-PV power forecast for grid operators



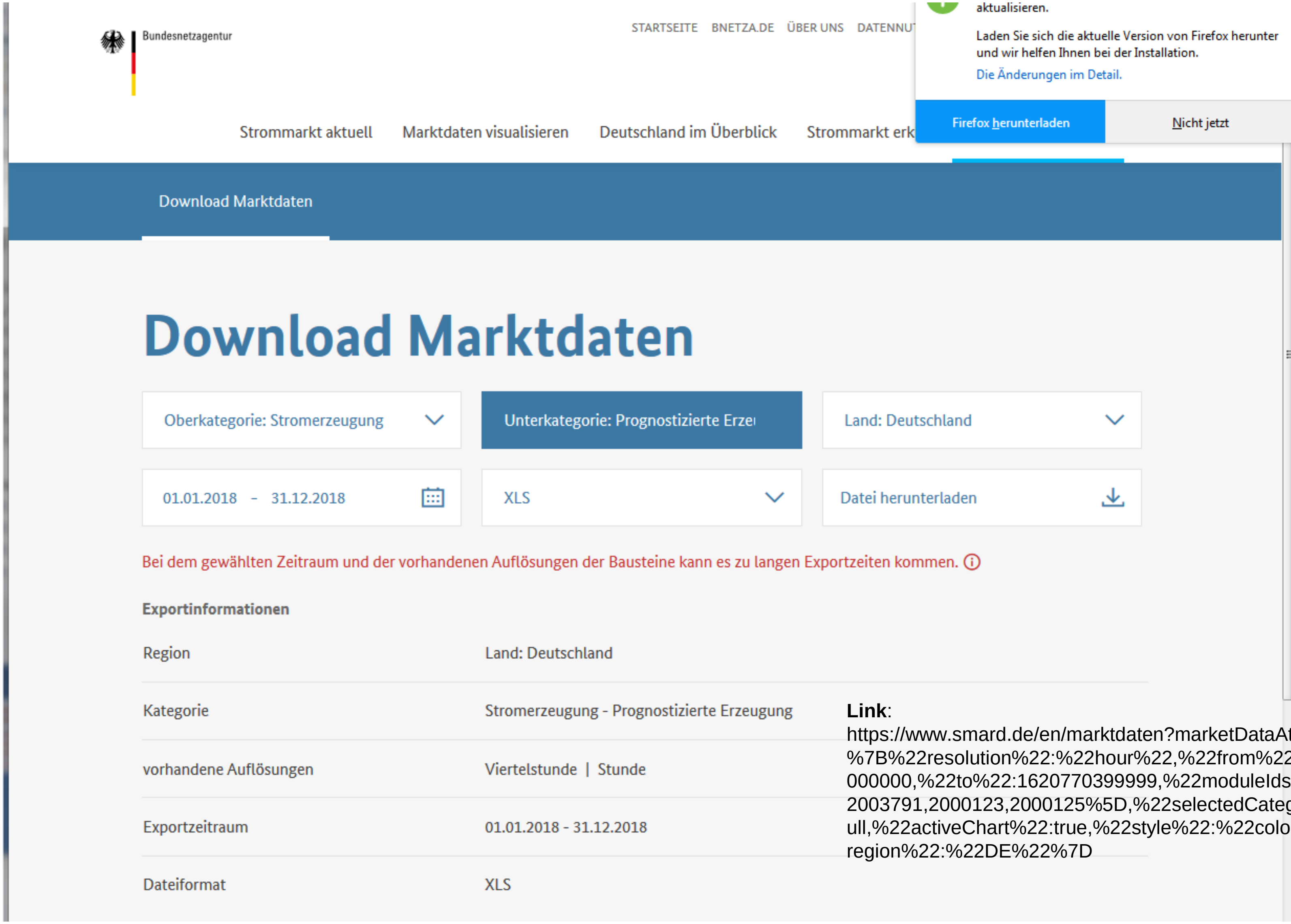
Detailed description

- Current forecast (last update)
- Intraday forecast at 8.00
- Day ahead forecast at 18.00

Tennet in Germany for the 22nd March 2017

https://transparency.entsoe.eu/generation/r2/dayAheadGenerationForecastWindAndSolar/show?name=&defaultValue=false&viewType=GRAPH&areaType=CTA&atch=false&datepicker-day-offset-select-dv-date-from_input=D&dateTime.dateTime=01.06.2015+00:00|UTC|DAYTIMERANGE&dateTime.endDateTime=01.06.2015+00:00|UTC|DAYTIMERANGE&area.values=CTY|10Y1001A1001A83F!CTA|10YDE-EON------1&productionType.values=B16&productionType.values=B18&productionType.values=B19&dateTime.timezone=UTC&dateTime.timezone_input=UTC

Forcast data for Germany → LINK



Link:
https://www.smard.de/en/marktdaten?marketDataAttributes=%7B%22resolution%22:%22hour%22,%22from%22:1619820000000,%22to%22:1620770399999,%22moduleIds%22:%5B2003791,2000123,2000125%5D,%22selectedCategory%22:null,%22activeChart%22:true,%22style%22:%22color%22,%22region%22:%22DE%22%7D

Photovoltaic gradients in the 50Hertz grid area

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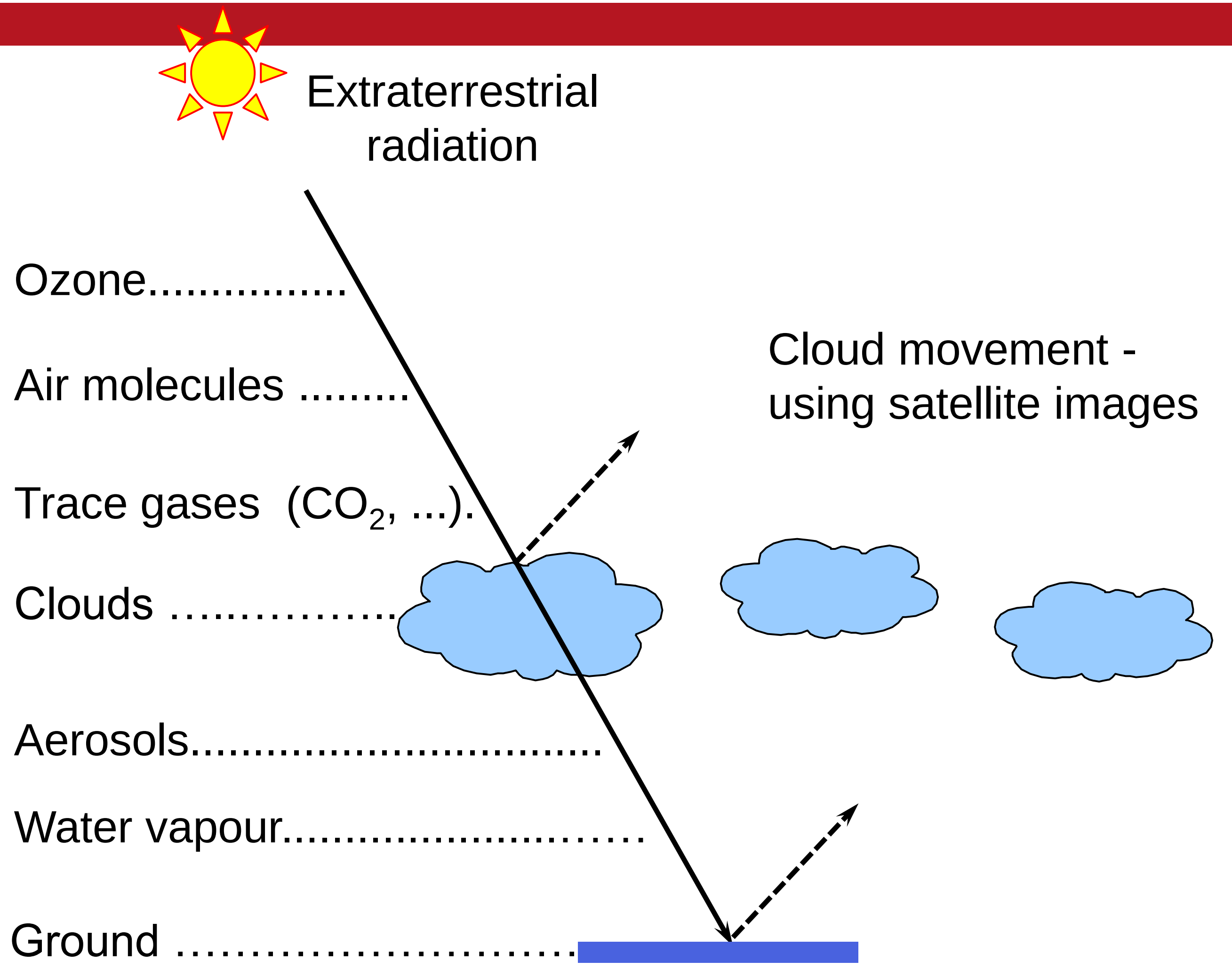
Description	2015	2016	2017	2018	2019	2020
Largest quarter-hourly jump in Photovoltaics	+1,061 MW / -709 MW	+860 MW / -576 MW	+595 MW / -600 MW	+826 MW / -655 MW	+645 MW / -626 MW	+1,054 MW / -769 MW
Largest hourly jump in Photovoltaics	+3,170 / -2,085 MW	+2,005 MW / -1642 MW	+1,875 MW / -1,824 MW	+2,041 MW / -1,950 MW	+2,222 MW / -2,132 MW	+2,412 MW / -2,345 MW
Installed capacity of Photovoltaics power plants at the end of the year	8,828 MW	9,279 MW	10,385 MW	11,443 MW	12,204 MW	13,552 MW
Maximum Photovoltaics infeed	5,995 MW	6,576 MW	7,200 MW	8,087 MW	8,038 MW	9,166 MW

Source:https://www.50hertz.com/en/Transparency/GridData/Production/Photovoltaics, May 2021

PV weather to power model

PV forecast: atmospheric extinction



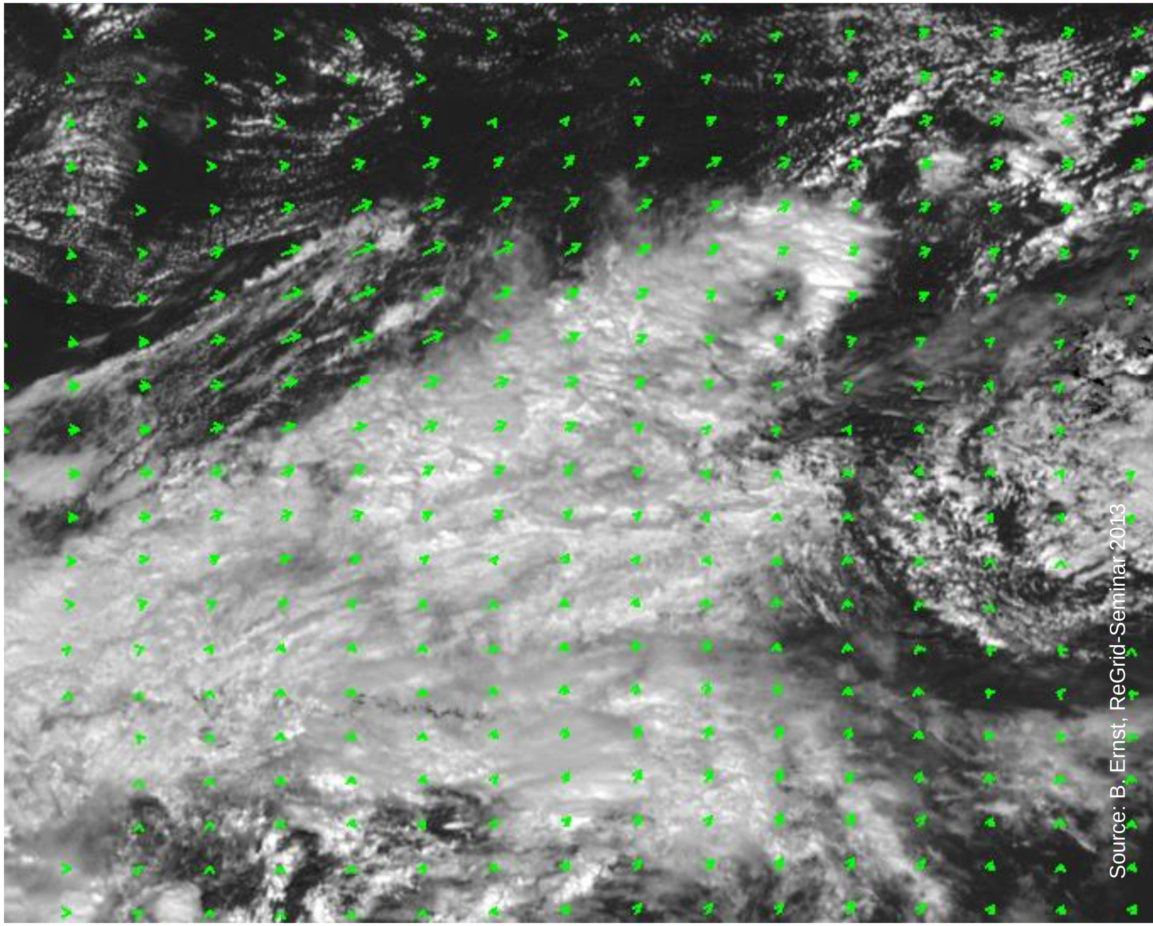
Source: B. Ernst, ReGrid-Seminar 2013 changes added by RENAC 2017

Source: PV Forecast – University of Oldenburg, Source: E. Lorenz and changes added by RENAC 2017

Irradiance prediction based on satellite data

- Cloud detection based on Meteosat satellite images
- Detection of cloud motion
- Extrapolation of cloud motion to predict future cloud situation
- Irradiance calculation from predicted cloud images

Meteosat Second Generation (high resolution visible range)



PV Forecast – University of Oldenburg, Source: E. Lorenz

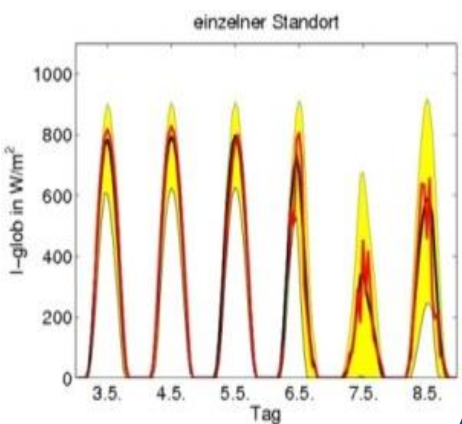
Weather to PV power model

Irradiance measurement

Satellite data

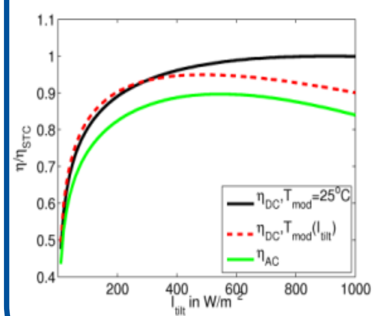
Numerical weather prediction

Irradiance prediction for specific representative sites (W/m^2)

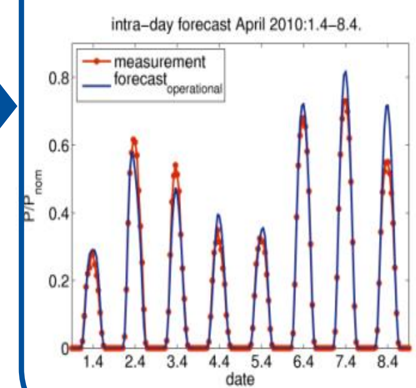


PV module technical data, tilt, orientation, losses and nominal power

PV module power output simulation and up-scaling

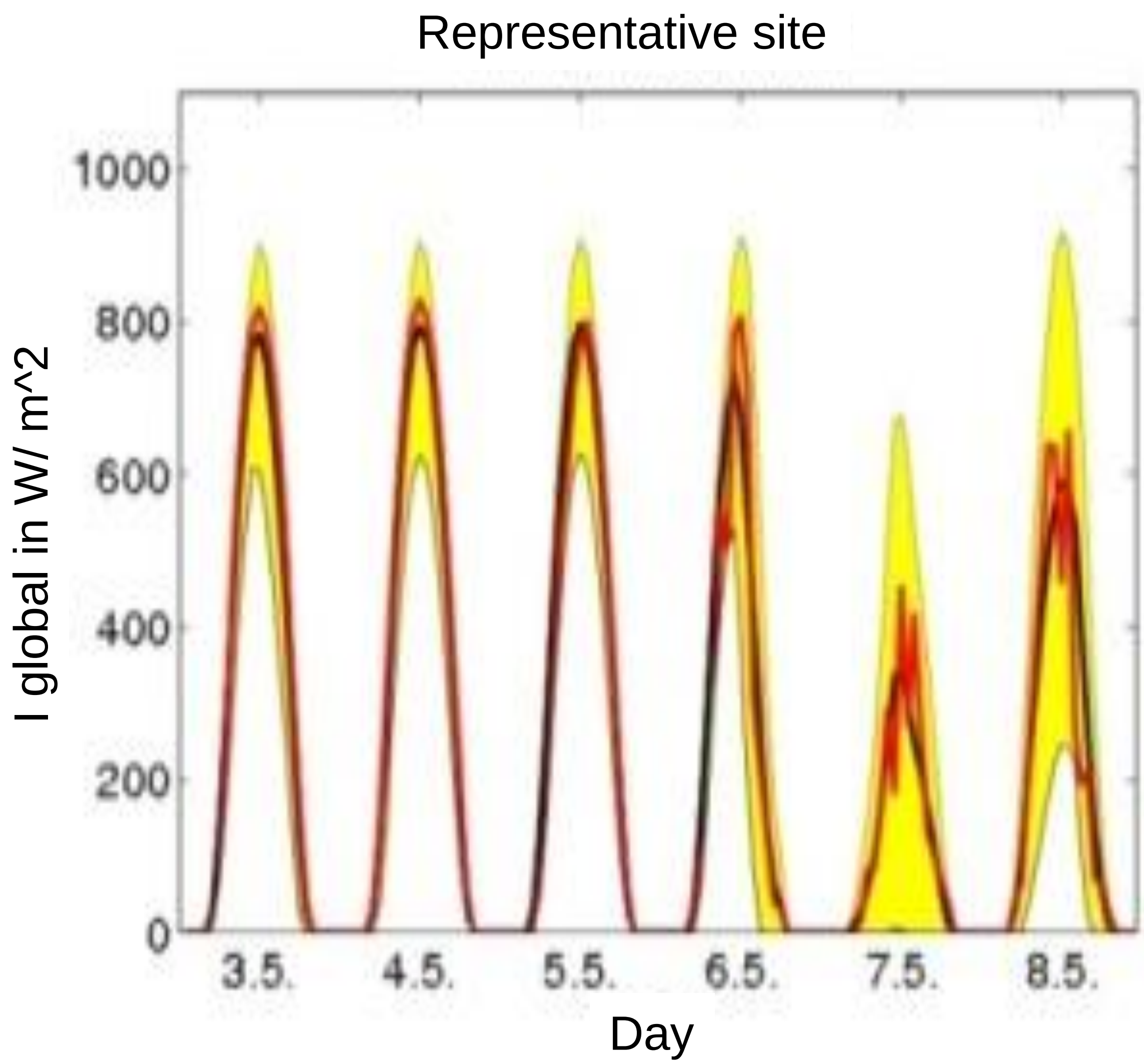


Regional PV power prediction



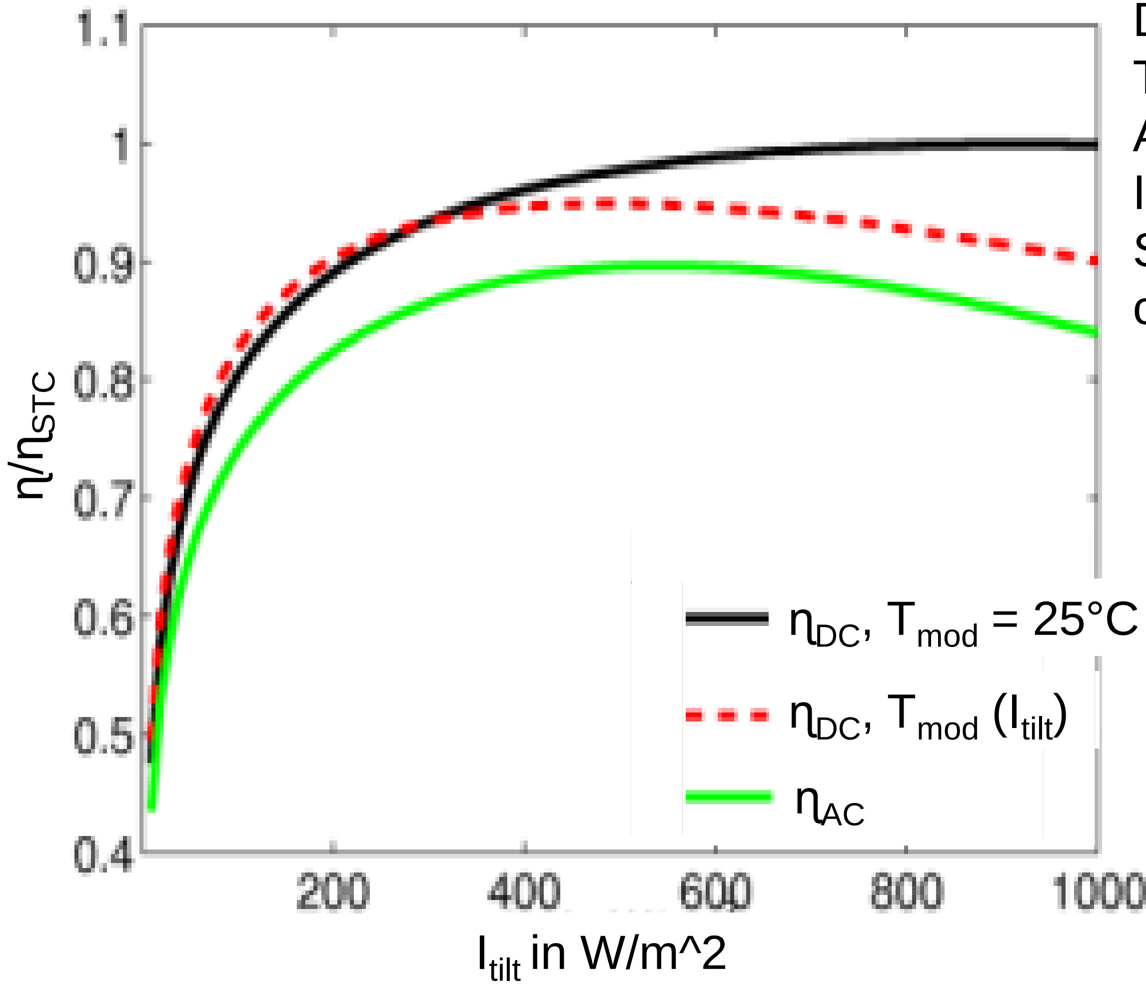
Source: E. Lorenz and changes by RENAC

Weather to power model– physical approach



Source: E. Lorenz and changes by RENAC

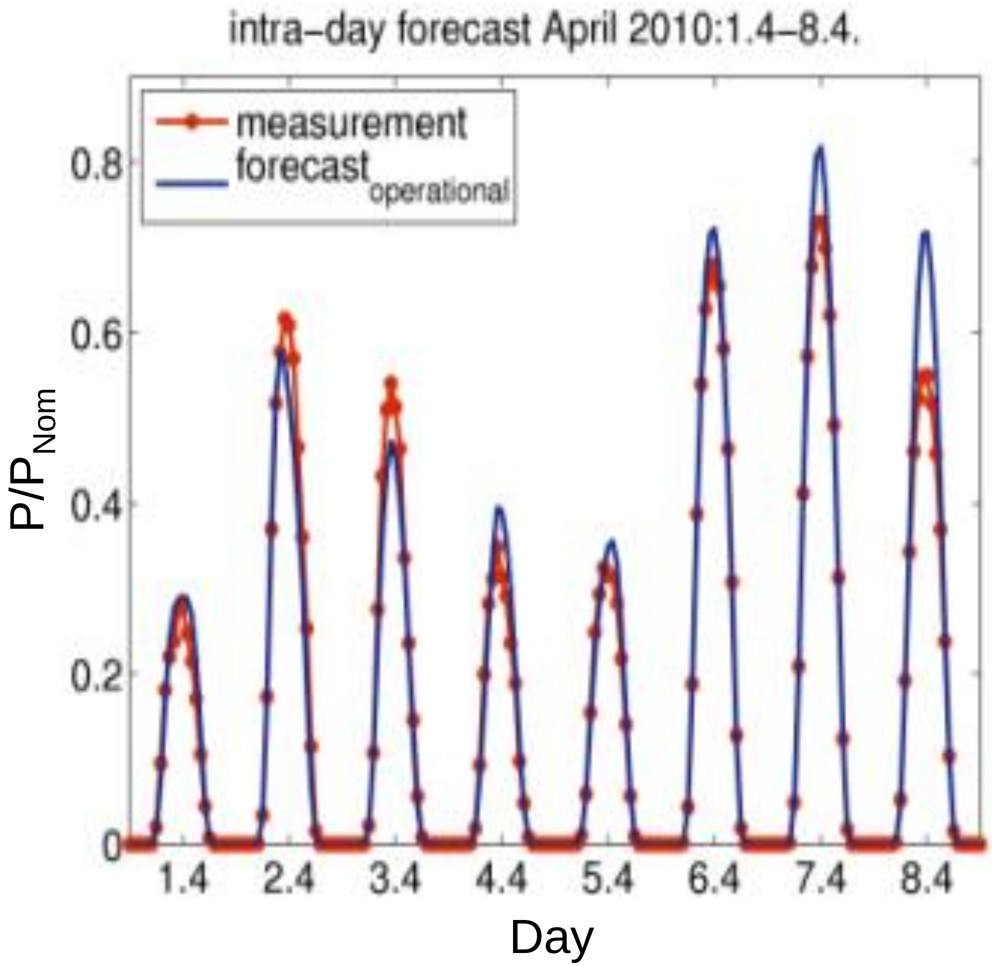
Weather to power model– physical approach



η = efficiency
DC = direct current
T_{mod} = temperature module
AC = alternating current
I_{tilt} = Irradiation at tilt angle
STC = Standard test conditions

Source: E. Lorenz and changes by RENAC

Weather to power model– physical approach



Source: E. Lorenz and changes by RENAC

Challenges of rooftop PV forecast

- Lack of information on the exact location, orientation and run times of small solar PV facilities.
- Many older or smaller pv facilities do not provide live feed-in data
- Many smaller solar PV panels are installed "behind the meter" (BTM). This means that all or some of the power is used locally and it is difficult to predict how much – if any – will be fed into the grid

https://www.cleanenergywire.org

Forecast errors

Definition of PV forecast error

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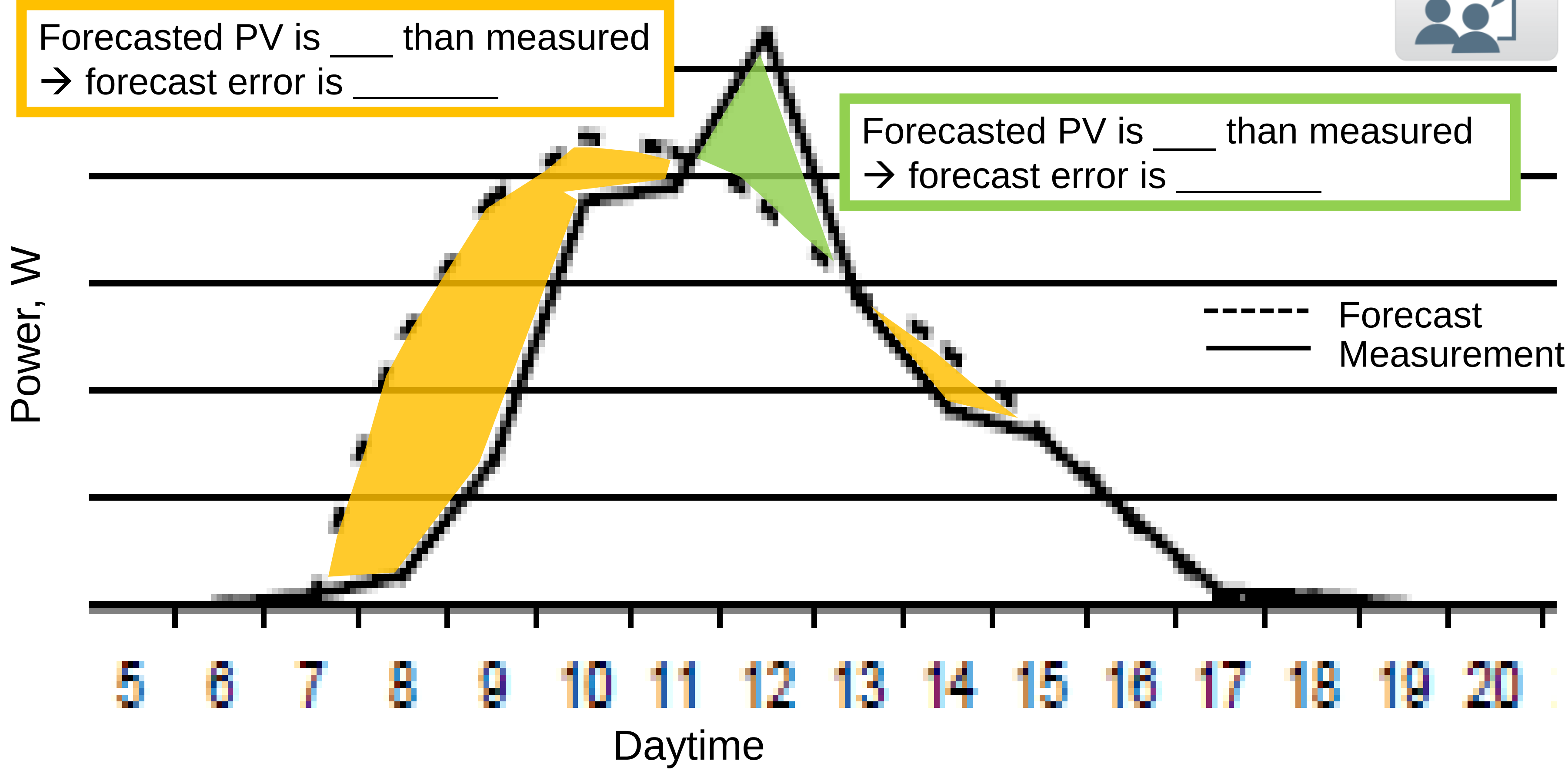
- Error = Forecast – Measurement

- Positive error → Overestimation
- Negative error → Underestimation

Source: B. Ernst, ReGrid-Seminar 2013

Exercise: Positive or negative forecast error

- PV day ahead forecast and online feed-in (measurement)



Source: Bing, 2005, explanaaiton and clulors added by RENAC

Solar-PV forecast and current infeed

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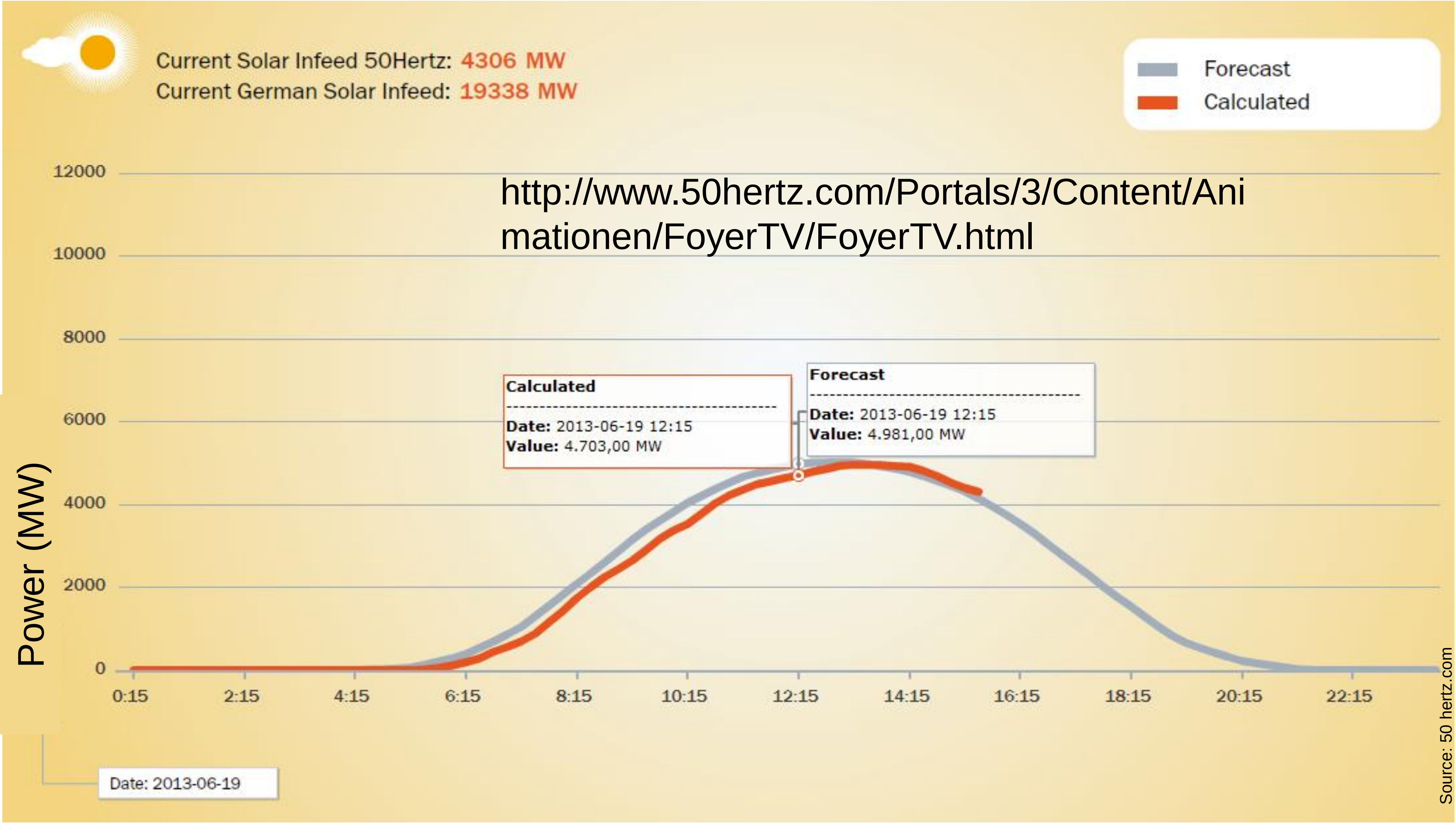
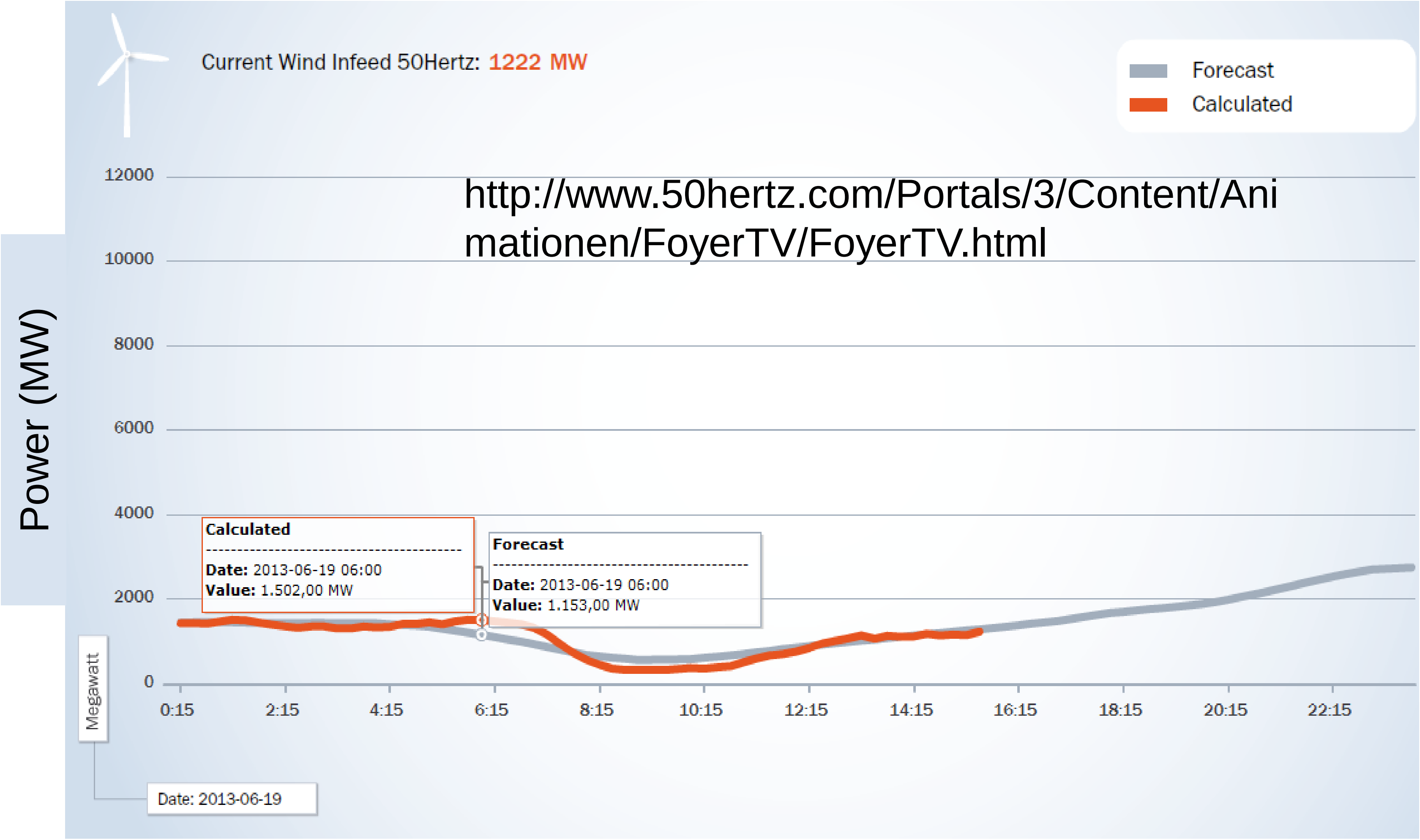


http://www.50hertz.com/Portals/3/Content/Animationen/FoyerTV/FoyerTV.html

Source: 50 hertz.com

Wind power forecast and current infeed



http://www.50hertz.com/Portals/3/Content/Animationen/FoyerTV/FoyerTV.html

Source: 50Hertz.com

Evaluation of forecast error

- **Definition of forecast error** (other definition is possible but has to be stringent)
  - Error = Forecast – Measurement
  - Positive error → Overestimation
  - Negative error → Underestimation
- In most literature **errors are normalized to installed capacity**

  + normalized to a fix value

  + site and weather independent

  + common practice in PV and wind business

  - errors look small at first sight.

- Normalizing to measured value

  + common practice at load forecast

  - normalized to a varying number,
  - calculated error at low PV or wind situation is very high although absolute error is small and error is not harmful for the system

- Normalizing to mean value

  + normalized to a fix number, high and low PV or wind situations are comparable

  - quotient can be calculated only with many data / after a period of time. It depends on weather and site.

Source: B. Ernst, ReGrid-Seminar 2013

Exercise: Normalisation of forecast error

- Installed capacity 10000 MW
- Forecast 2000 MW
- Real feed in 3000 MW
- Forecast Error -1000 MW
- Error normalised to installed capacity -1000 MW / _____ MW = ___%
- Error normalised to real feed-in -1000 MW / _____ MW = ___%
- Error normalised to forecast -1000 MW / _____ MW = ___%

Exercise: What could be the reasons for the following four situations with forecast errors?

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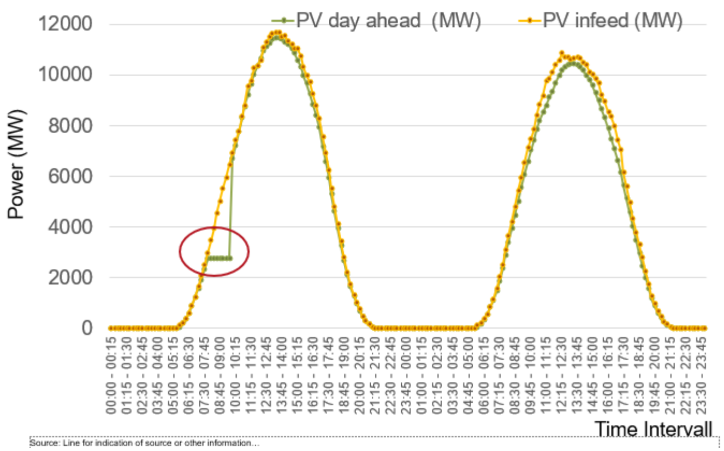
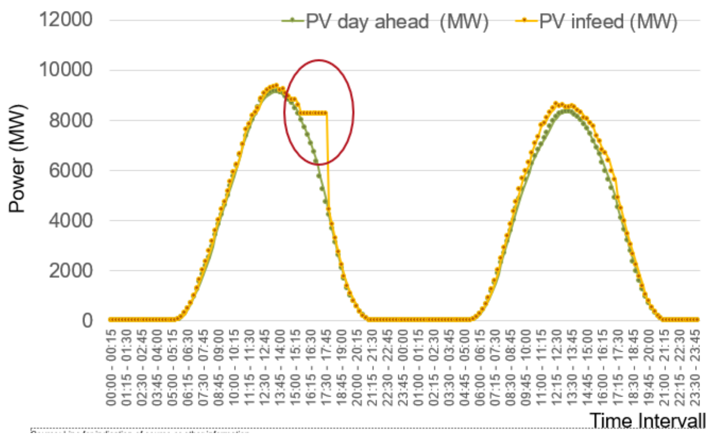
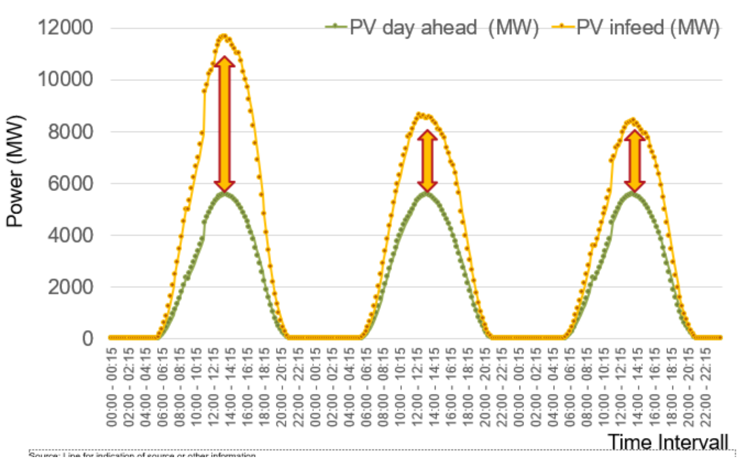
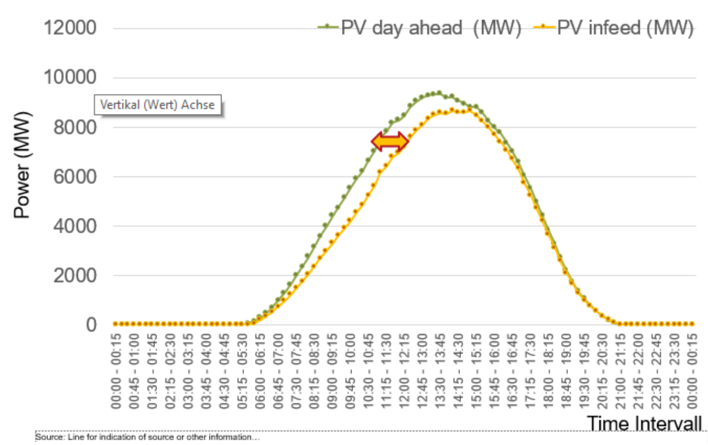
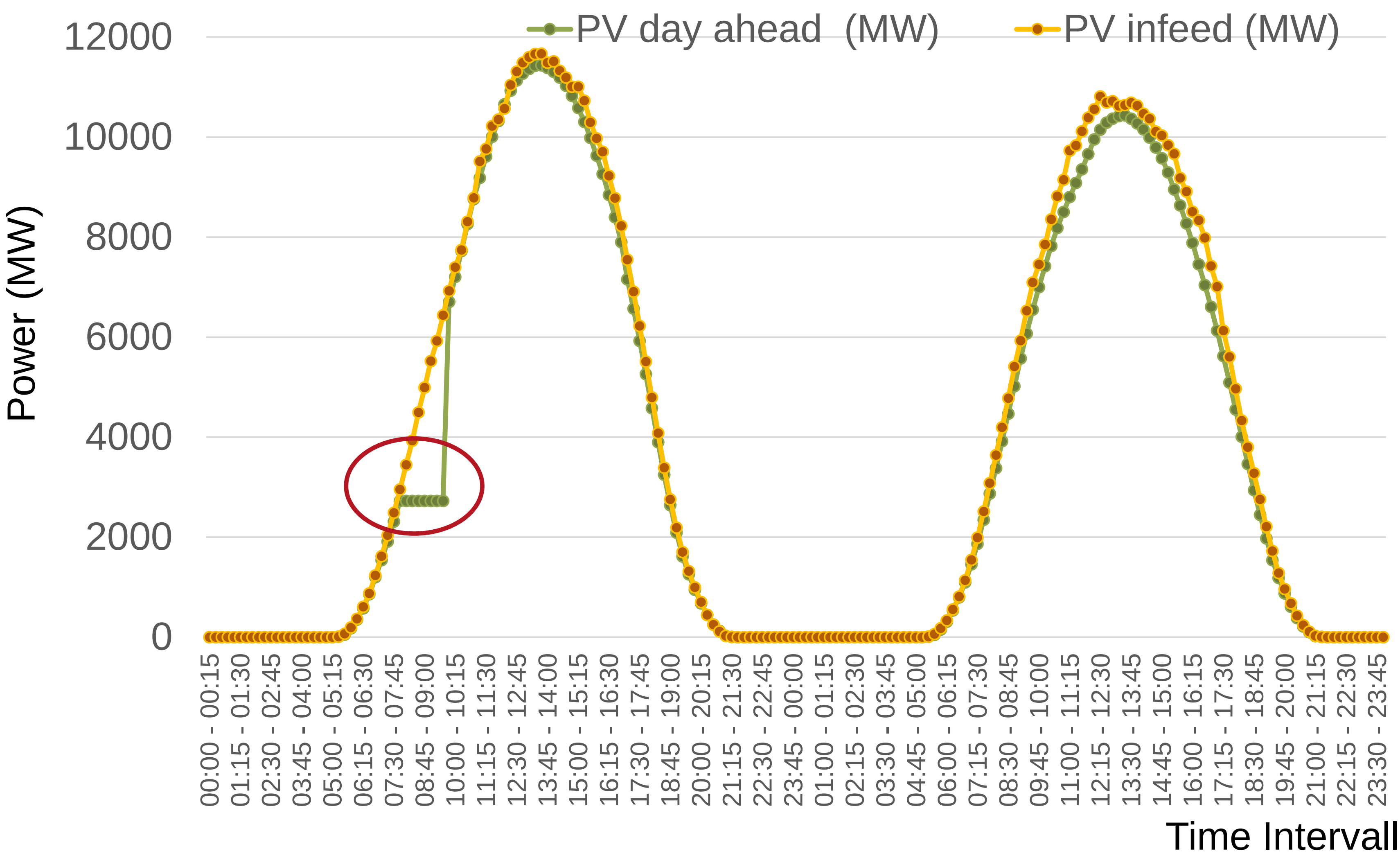




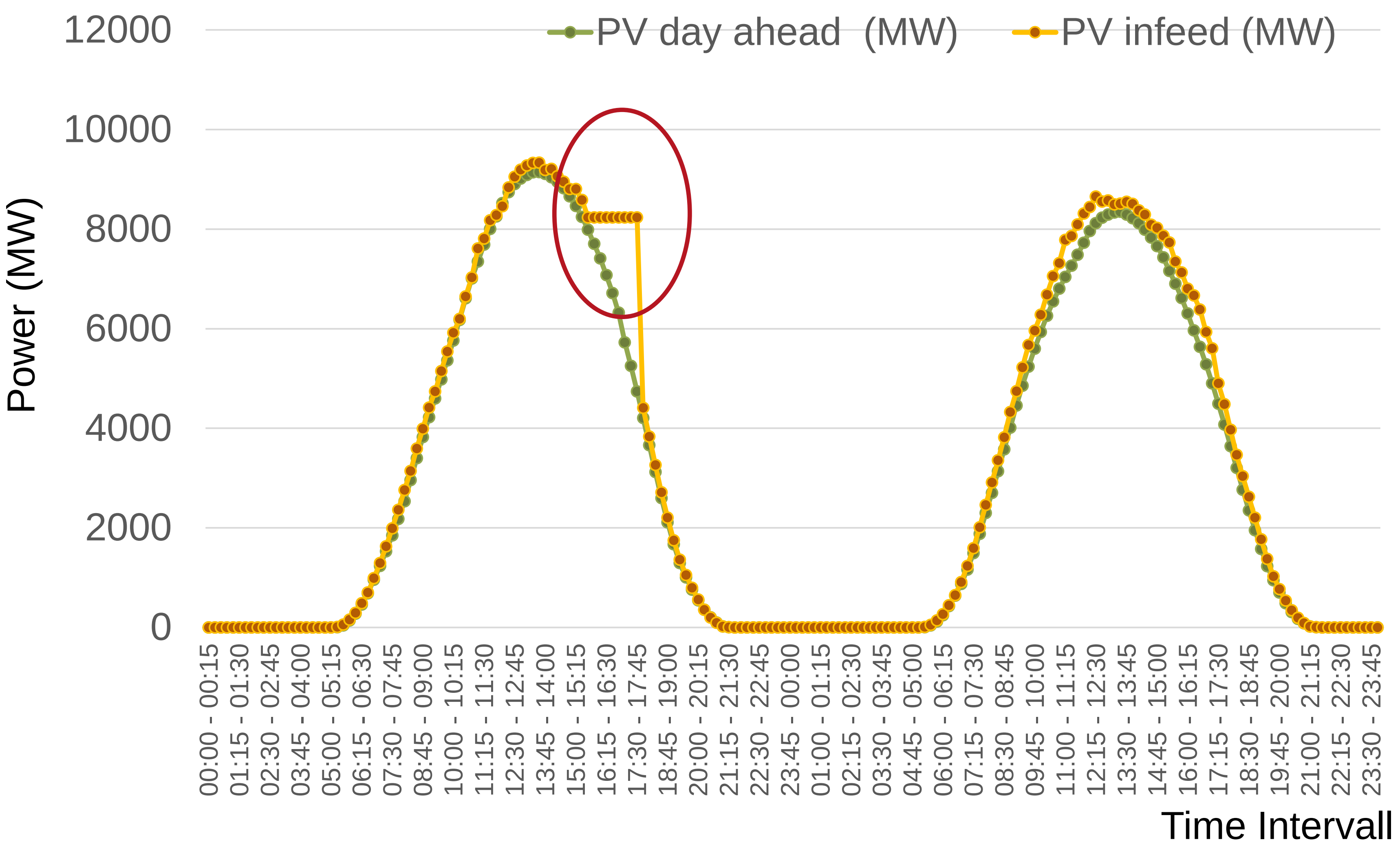




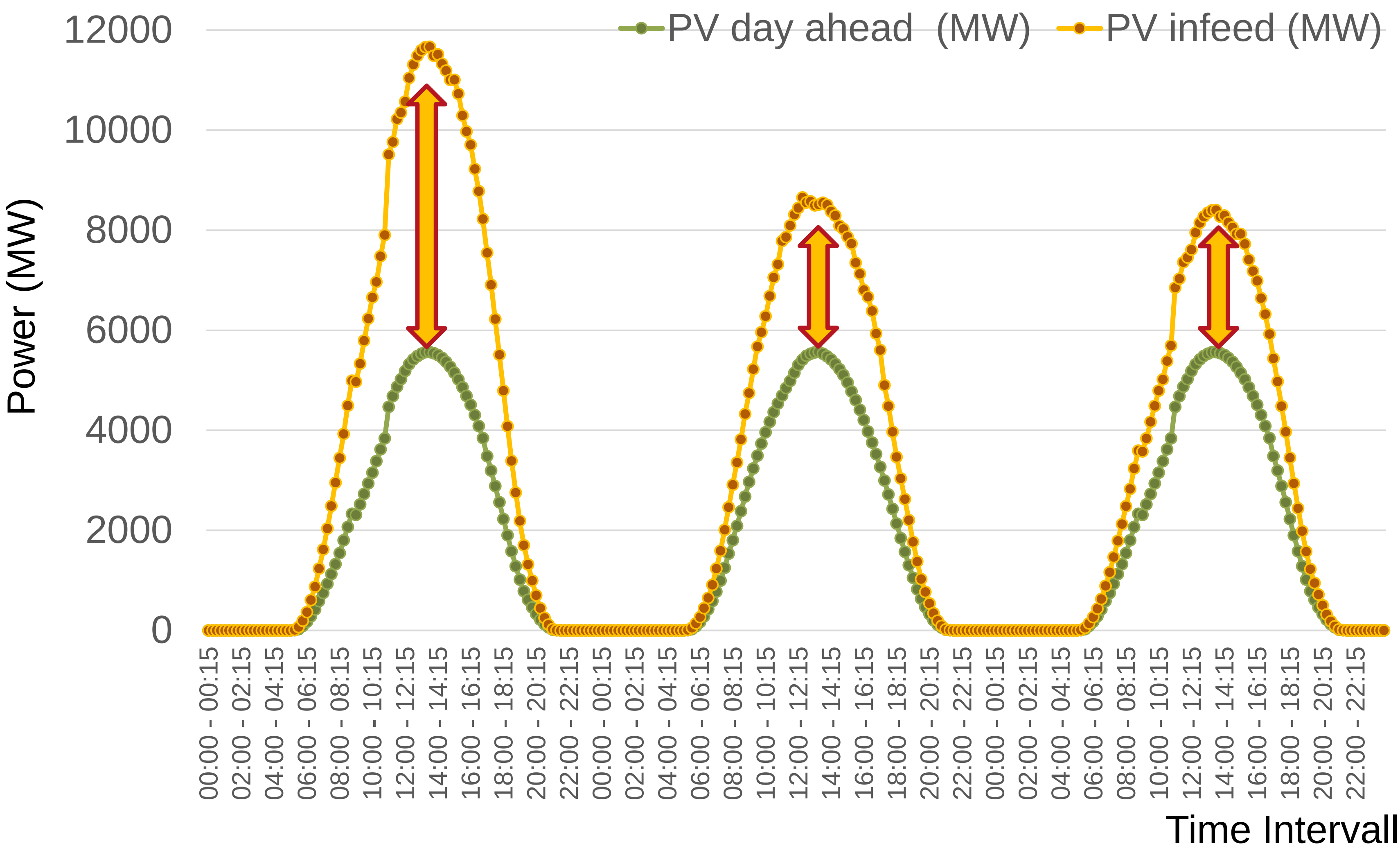
Forecast error



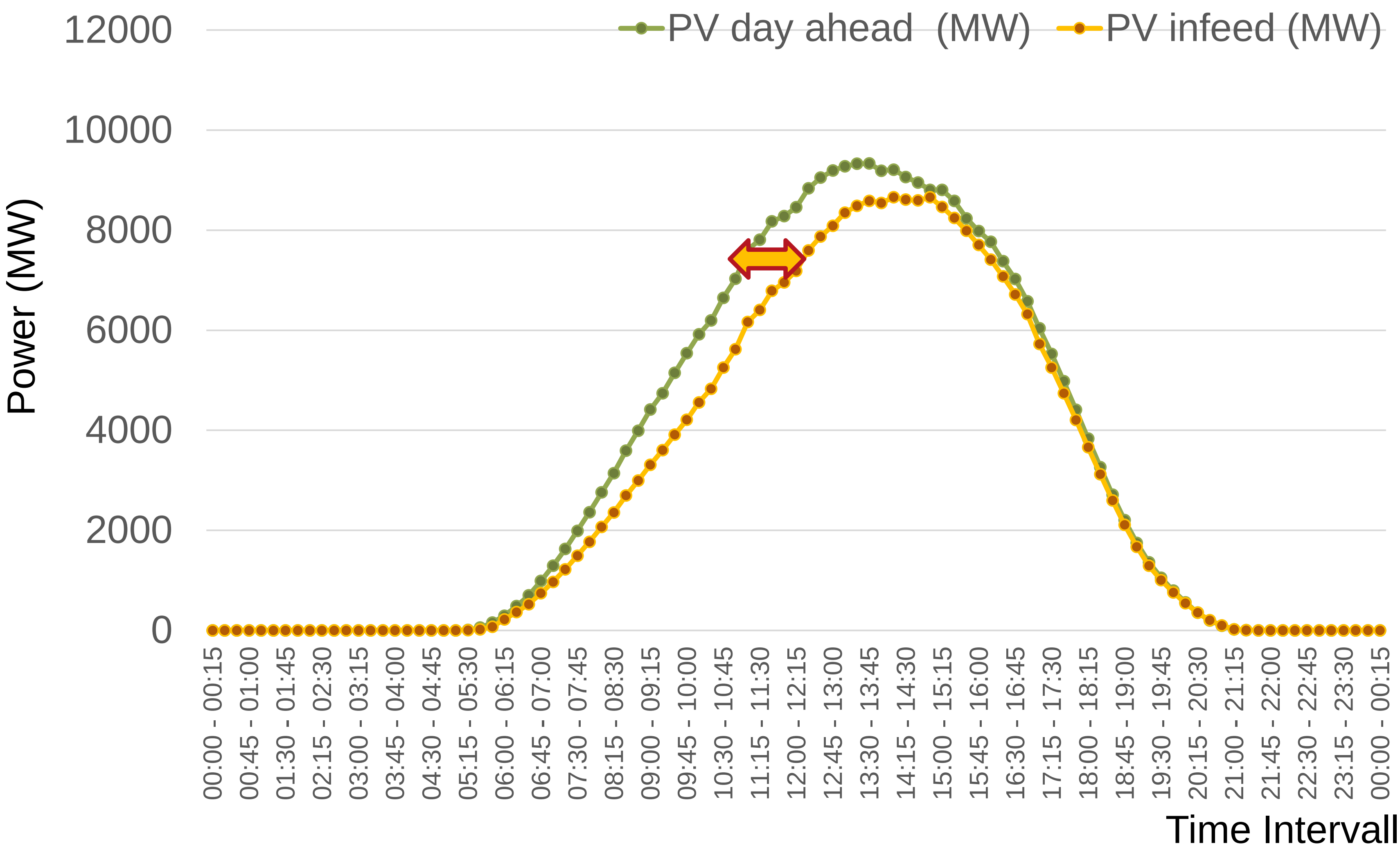
Forecast error



Forecast error



Forecast error



Exercise: Calculate forecast errors 1 / 2

- Assumptions:
  - The installed wind power capacity in the grid control area is 12500 MW.
  - Two different forecast providers (called A and B) forecasted the wind power for the next day.
  - The real feed in was 8000 MW.
  - The tow forecast providers made different errors (% overestimation normalised to installed wind capacity):
    - Forecast service provider **A** has a forecast error of 6%.
    - Forecast service provider **B** has a forecast error of 4%.

Exercise: Calculate forecast errors 2 / 2

- Please calculate the absolute forecast error (MW) of forecast provider A and B

	Absolute forecast error (MW)
Forecast provider A	
Forecast provider B	

- Please calculate the amount of power (MW) that forecast provider A and B forecasted.

	Forecasted feed-in (MW)
Forecast provider A	
Forecast provider B	

PV forecast error distributions examples for two distribution grids

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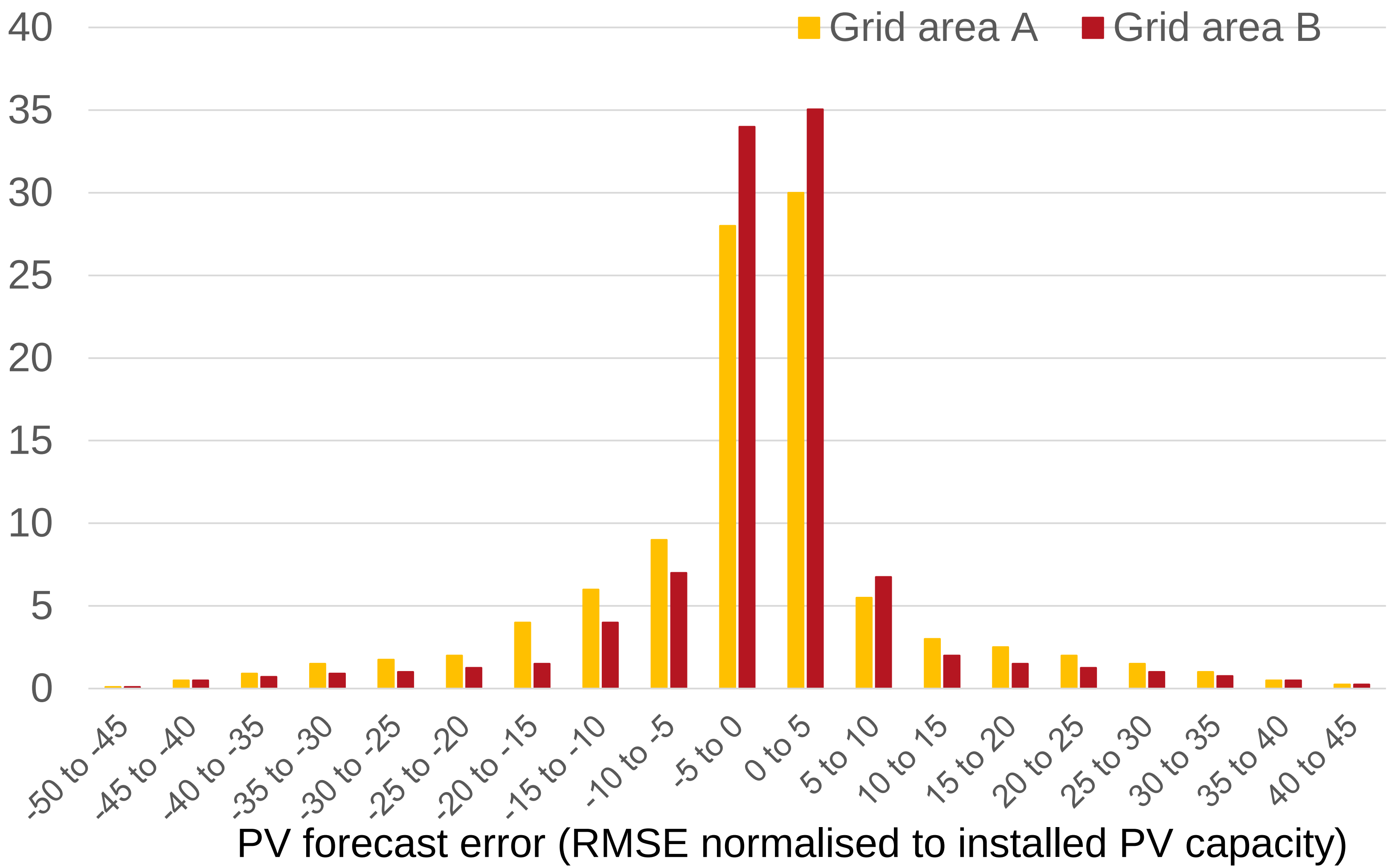

Soure: internal data

Solar forecast error distribution at different geographic forecast region sizes (single plant to 1500 km)

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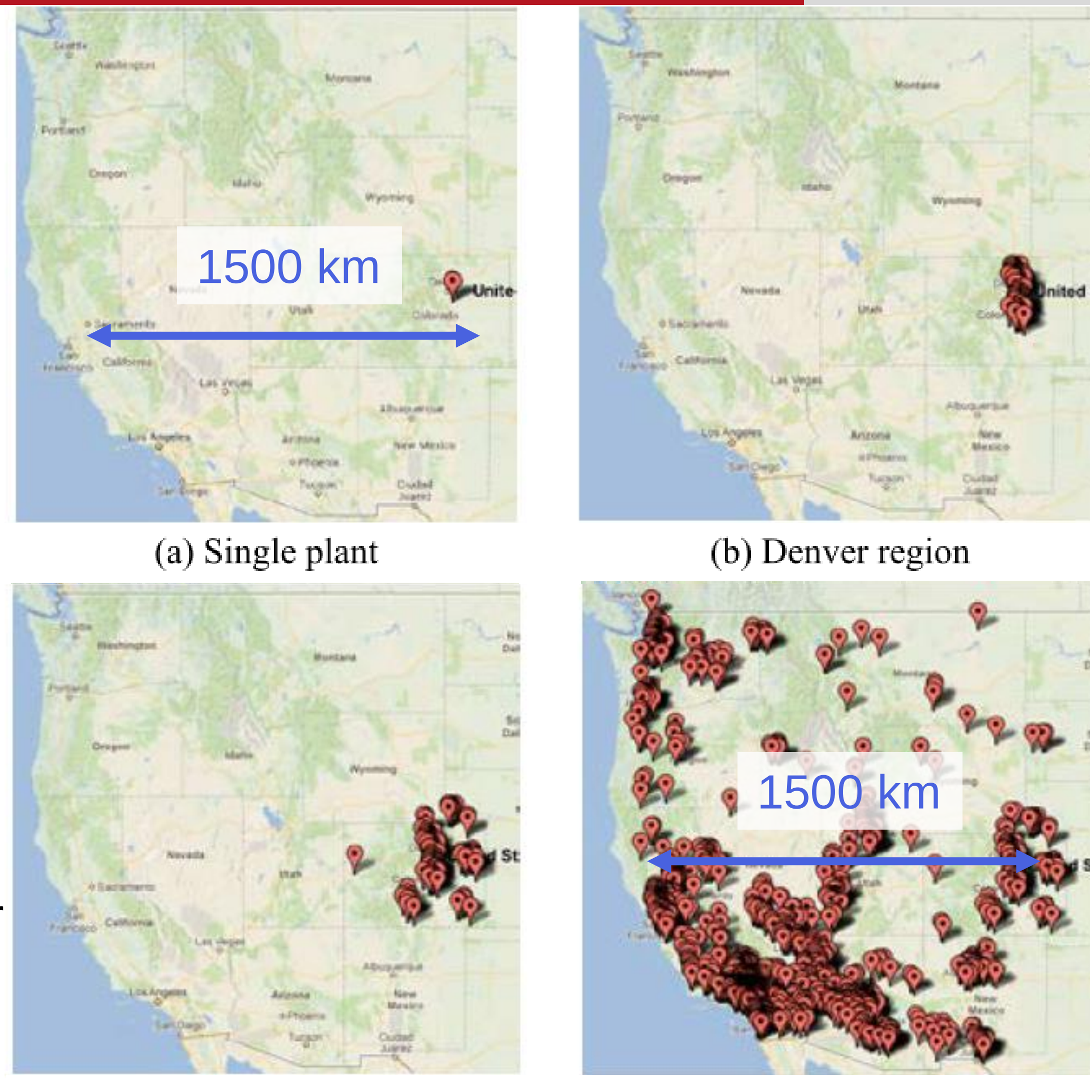
- Study analysed the 1-hour-ahead forecasting and the day-ahead forecasting for 4 regions:
  a) Single plant
  b) Region of Denver (US)
  c) State Colorado (US)
  d) Western area of the US with a diameter of ca. 1500 – 2000 km
- Analysis compared the forecast error distribution (normalised forecast error over probability density)



(a) Single plant

(b) Denver region

(c) State of Colorado region

(d) Western Interconnection

J. Zhang et al "Metrics for Evaluating the Accuracy of Solar Power Forecasting" NREL/CP-5500-60142, 2013

Solar forecast error distribution at different geographic forecast region sizes (single plant to 1500 km)

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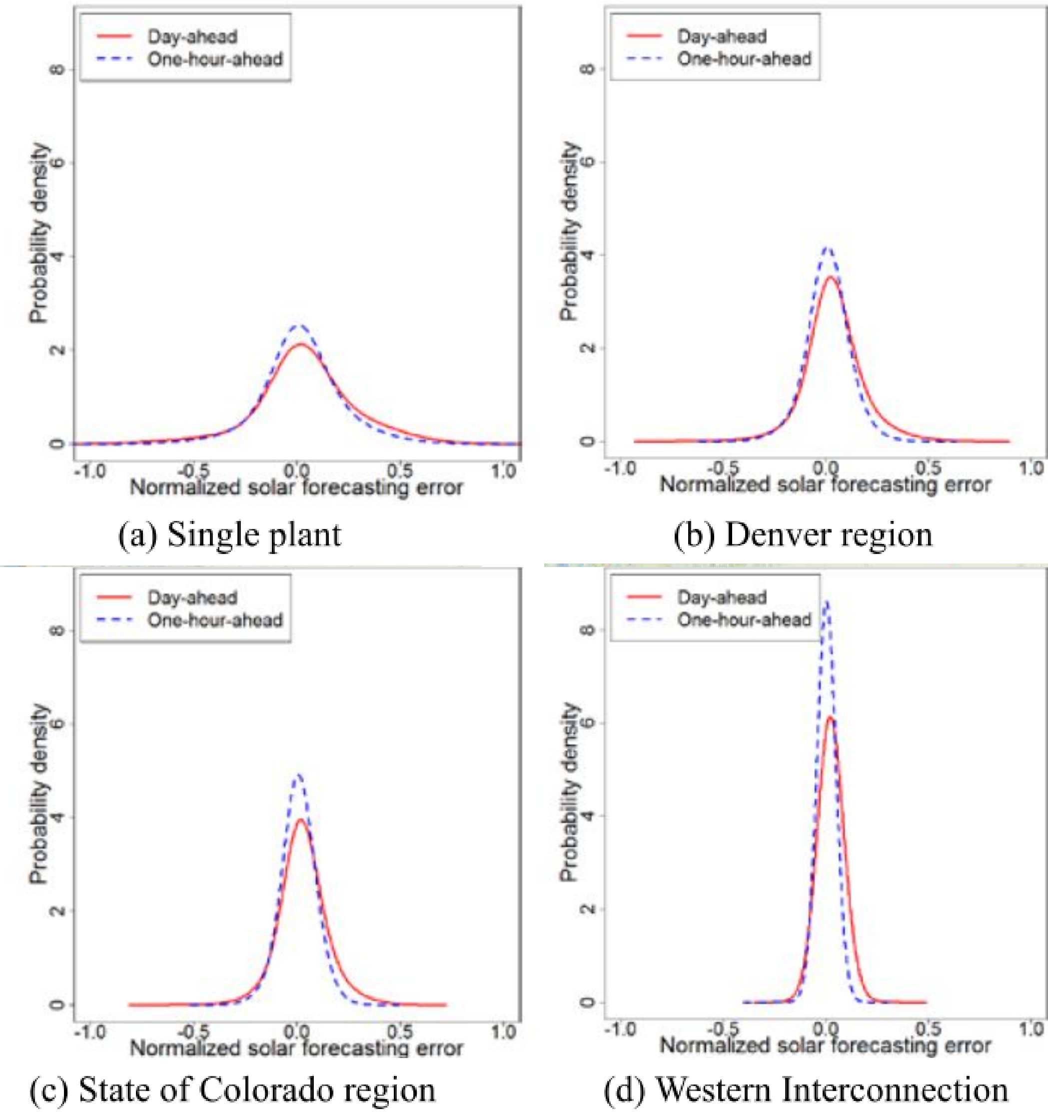
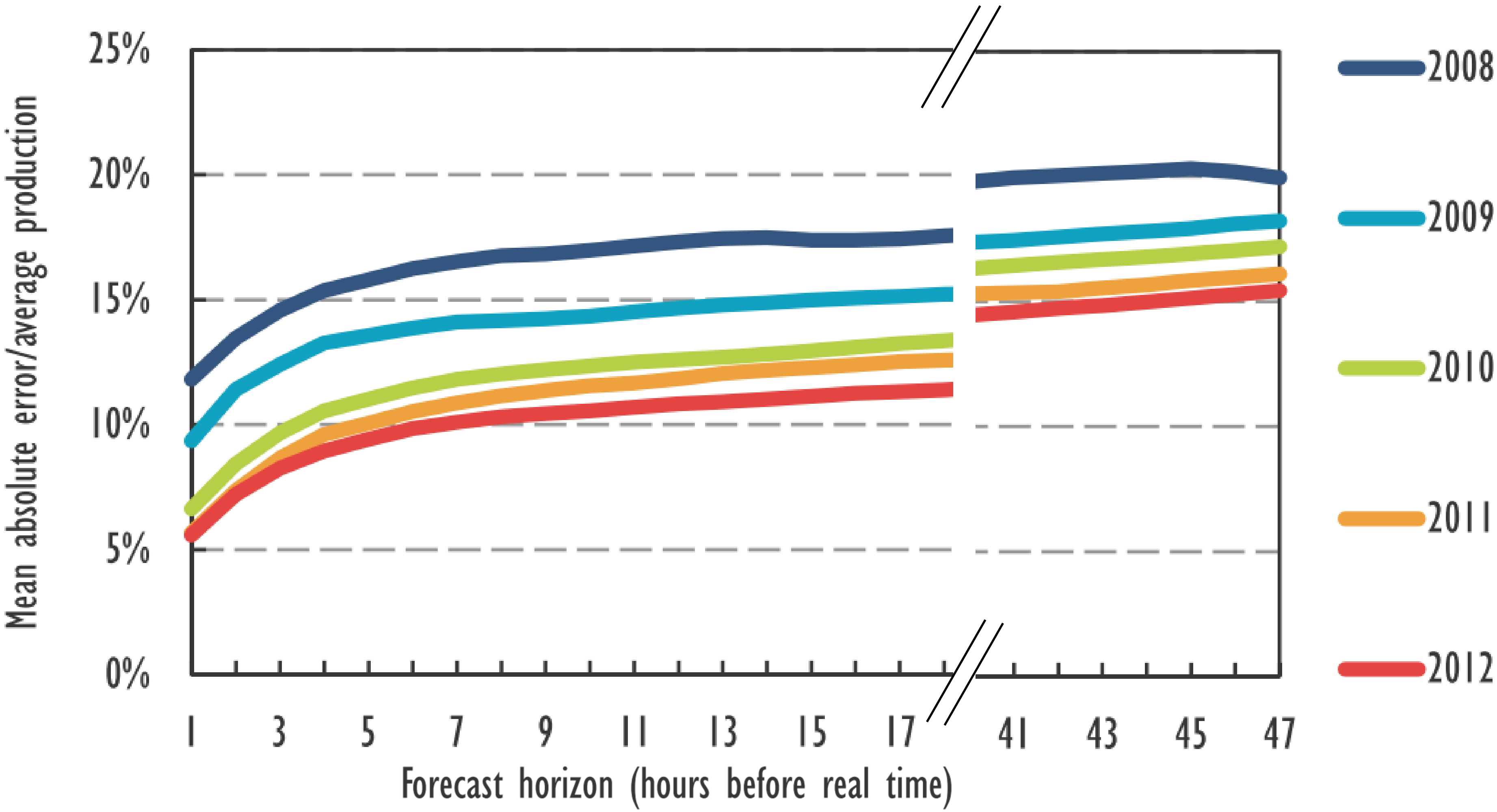
- Distributions of normalised forecast error over probability density at four regions, results:
- Single plants have the largest forecast error
- The larger the forecast region the smaller the forecast error
- Larger geographic area ha a more pronounced peak and slimmer shoulders.
- 1-hour-ahead forecasting (red) performs better than the day-ahead forecastin (blue) in all regions.



(a) Single plant
(b) Denver region
(c) State of Colorado region
(d) Western Interconnection

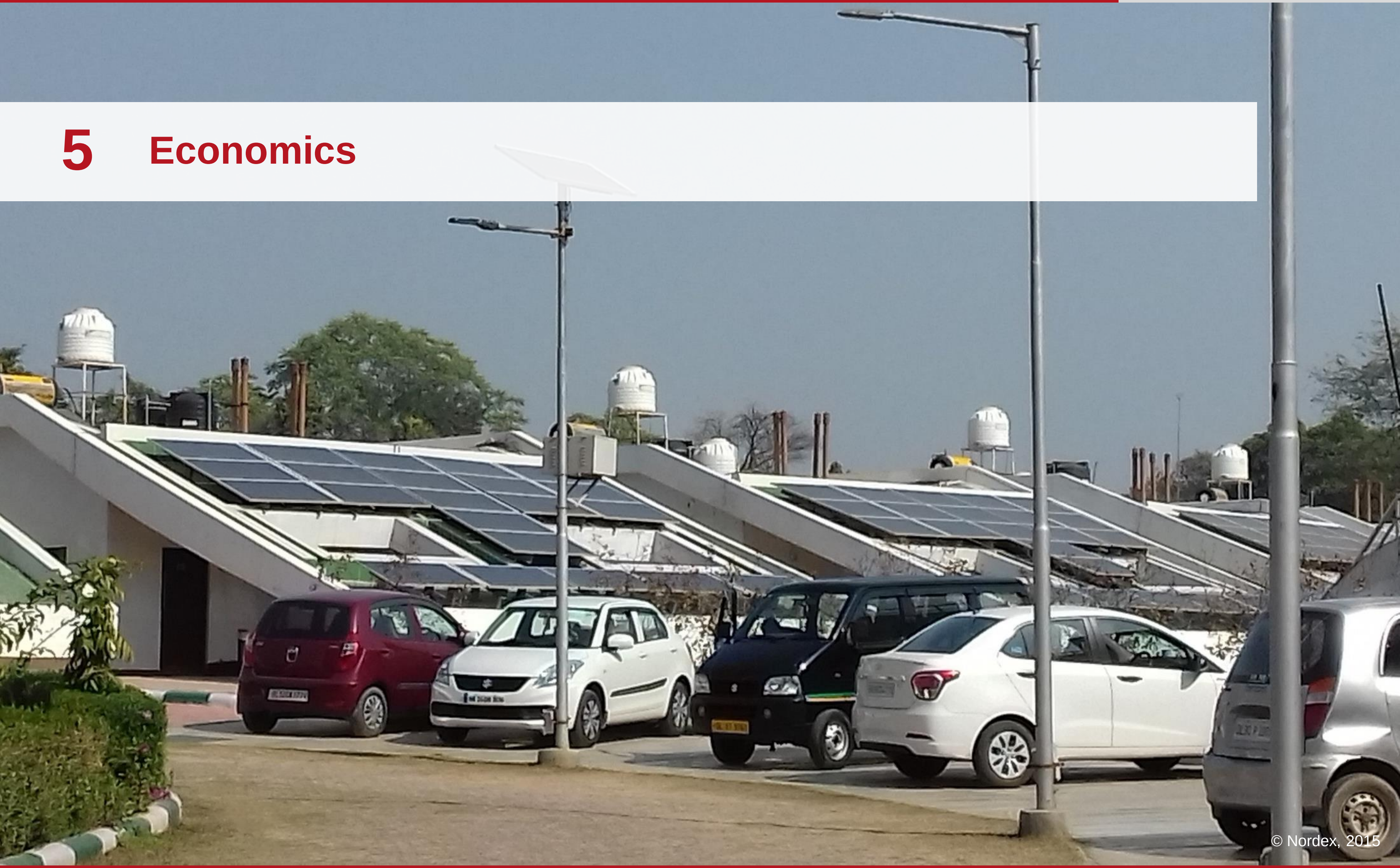
J. Zhang et al "Metrics for Evaluating the Accuracy of Solar Power Forecasting" NREL/CP-5500-60142, 2013

Improvement in wind power forecasts in Spain, 2008-12



Source: IEA „The Power of Transformation“, Figure 2.9, Paris 2014

5 Economics



Economics of forecasting models

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- Costs vary between some 10,000 € /year for single site up to several 1,000,000 €/year for whole control area / country
- Costs are driven by
  - Input data (NWP); e.g. GFS free
  - Number of NWP used
  - Frequency of updates
  - Costs for communication; e.g. email, leased line
  - Use of measurements for validation
  - Use of measurements for frequent updates (now casting)

Source: B. Ernst, ReGrid-Seminar 2013

Example: PV power forecast for a German TSO

- 5 different companies provide PV power forecasts for the transmission grid operator (TSO)
  - 4 observed areas:
    - Germany
    - control area
    - regional distribution gird operators (DSO) areas and
    - TSO grid nodes
  - PV forecast intervals:
    - 4 days ahead at 8 a.m. and 2 p.m.
    - 3-, 2- and 1-day(s)) ahead at 8 a.m. 2 p.m. and 8 p.m.
    - Intraday short term forecast (h-4, h-2 and h-1)
- TSO combines the forecasts according to provider accuracy
- Night hours are excluded from RMSE calculation

Source: GridLab, Müller Mienack. 2017

Exercise: Economics of forecasting

- Assumptions:
  - The grid operator has the task to sell the PV power on the energy markets. The grid operator sells the power on the day ahead market for 50 €/MWh. In case of a forecast error the grid operator has to buy balancing power on the intra-day market for 125 €/MWh. →This means in case the grid operator sold more power on the day ahead market that the grid operator can finally deliver to the market and the grid operator has to buy expensive balancing power on the intra-day market.
  - Two forecast providers forecasted the PV power for the next day from 10 a.m. to 3 p.m. (5 hourly blocks). They have a different forecast error (% overestimation of installed PV capacity):
    - Forecast service provider **A** forecasted 8750 MW (forecast error of 6%).
    - Forecast service provider **B** forecasted 8500 MW (forecast error of 4%).
  - The installed PV power capacity in the grid control area is: 12500 MW

Exercise: Economics of forecasting

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- Task: Compare the forecast A and B by calculating the following
  - **Forecast error (MW)** = forecast error (%) x installed capacity (MW)
  - **Balancing power costs due to forecast error** = forecast error (MW) x balancing power costs (€/MWh) x duration of the error (h)
  - **Differences (€) due to wrong forecast** = balancing power costs forecast A (€) - balancing power costs forecast B(€)

Forecast providers (examples)

Brief list of forecasting models

- ANEMOS, Wind forecast: http://www.windpowerpredictions.com/index.html
- AWS Truepower www.awstruepower.com
- Climate Connect, Wind & PV power forecasts: https://www.climate-connect.com/forecasting.php
- Enercast, Wind & PV power forecasts: https://www.enercast.de/
- Energy & meteo systems, Wind and PV, www.energymeteo.de
- Energy weather, Wind & PV forecast: https://www.energyweather.com/en/renewable-forecasts.html
- ENFOR (ENFOR), Wind & PV power forecasts: http://www.weprog.com/home
- Eurowind (EuroWind GmbH) www.eurowind.info
- EWC Weather Consult GmbH www.weather-consult.com
- FLOWSTAR-Energy (CERC), Wind power forecasts: https://www.cerc.co.uk/forecasting.html
- Forecaster (DNV.GL), Wind & PV power forecasts: https://www.dnvgl.com/services/forecaster-introduction-3848
- Manikaran analytics, Wind & PV power forecasts: http://www.manikarananalytics.in/
- Meteo Media www.meteomedia-energy.de
- Meteocontrol, PV forecast www.meteocontrol.de

Brief list of forecasting models

- Meteologica, Wind and PV power forecast, www.meteologica.com
- MetraWeather, Wind forecast: https://metraweather.com/energy/weather-services-for-energy-generators-retailers
- METROLOGICA, Wind & PV power forecasts: http://www.meteologica.com/services.html
- MSEPS (WEPROG) www.weprog.com
- Overspeed, Wind & PV power forecasts: https://www.overspeed.de/en/solutions/wind-power-forecasts
- PowerSight, PV and Wind Forecasting (3Tier) www.3tier.com
- Reconnect energy, Wind & PV power forecasts: http://www.reconnectenergy.com/services/
- SIPREÓLICO, Statistics-based prediction tool developed by the University Carlos III, Madrid, Spain, statistical model, uses HIRLAM, wind forecast
- SOLCAST, PV power forecasts: https://solcast.com/
- Spotrenewables (EuroWind), Wind & PV power forecasts: https://spotrenewables.com/index.php
- WPMS (Fraunhofer IWES) www.iwes.fraunhofer.de
- WPPT (Wind Power Prediction Tool) / ENFOR http://enfor.eu/

Metrics for assessing solar forecasting accuracy

- Metrics for assessing solar forecasting accuracy must be useful for decision making of power system operators under the scenario of a high penetration of solar power. Possible metrics are:
  - statistical metrics including correlation coefficient, (normalized) root mean squared error (RMSE), maximum absolute error (MaxAE), mean absolute error (MAE), mean absolute percentage error (MAPE), mean bias error (MBE)
  - economic and reliability metrics, including non-spinning reserves service represented by e.g. 95th percentiles of forecast errors
  - variability estimation metrics, including different time and geographic scales, and distributions of forecast errors;
  - uncertainty quantification and propagation metrics, including standard deviation and information entropy of forecast errors
  - ramping characterization metrics

Zhang et al "Metrics for Evaluating the Accuracy of Solar Power Forecasting" NREL/CP-5500-60142, 2013

Group discussion – short term forecast implementation

Group work: Questions for PV forecast implementation

1. Why do distribution grid and transmission grid operators in Vietnam need a short term PV power forecast?
2. Which criteria could be used to compare and evaluate different forecast providers?
3. Which topics could be important to set up a contractual agreement with a forecast providers regarding
   - technically aspects and
   - performance / quality of forecast?

Summary

Summary: short term power forecast

- Wind and solar power varies fundamentally from conventional energy generation due to the fluctuation of the resource
- Short term wind and solar power forecast is a prerequisite for grid integration
- Wind and solar power forecast is needed to link weather dependant production with
  - Dispatch of conventional power plants (residual or net load calculation)
  - Load flow forecasts / grid operation
  - Operation of power/energy markets and
  - Maintenance of assets
- Accuracy of wind and solar power forecast influences the
  - Need for balancing power
  - Costs of system integration of PV and wind power

Thank you!

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Example: Wind power forecast for a German TSO

- 7 different companies provide wind power forecasts for the transmission grid operator (TSO)
  - 4 observed areas:
    - Germany
    - control area
    - regional distribution gird operators (DSO) areas and
    - TSO grid nodes
  - Wind forecast intervals:
    - 3-days ahead at 8 p.m
    - 2- and 1-day(s) ahead at 8 a.m. 2 p.m. and 8 p.m.
    - Intraday short term forecast updates (h-4, h-2 and h-1)
- TSO combines the forecasts according to provider accuracy

Source: GridLab, Müller Mienack. 2017

Wind power forecasts

- Time range of forecast: 0 to 10 days
- Temporal resolution: 5 minutes to 1 hour blocks
- Short term forecast: 6 to zero hours
- Update: several times a day to every 5 minutes
- Integration of online measurement data for optimization of prediction
- Prediction of wind power output for
  - entire countries or regions
  - designated control areas
  - individual grid nodes
  - individual wind parks

Source: https://www.energymeteo.de/produkte/leistungsvorhersage/windleistungsvorhersage.php